Public Patent Official Report (A)

(11) Publication number
08046186 A
(43) Date of publication of application: February 16, 1996

(51) Int. Cl.	Distinguished Number	Reference Number	F1
H01L 29/78			
H01L 21/28			
H01L 21/027			
H01L 21/3205			

Total page 8

(21) **Application number** 6-175526
(22) **Date of filing** July 27, 1994

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(54) Invention

Semiconductor Device

(57) Abstract

Purpose: To prevent hydrogen from being diffused into a gate insulating film with an antireflection film constituted of an SiOn thin film being kept existing by letting a gate electrode include a titanium layer.

Constitution: On an Si substrate 1 where element isolation regions 2 and a gate insulating film 3 are formed, a gate electrode 9 which is constituted of a polysilicon layer 4, a Ti layer 5 and a titanium silicide layer 6 which is put between the other two layers 4 and 5 is formed. On the gate electrode 9, an antireflection film 7 constituted of an SiOn system thin film is deposited in the same pattern as the gate electrode 9. Due to this structure, a hot carrier resistance is remarkably increased compared with the conventional MOS transistor which has no Ti layer 5 in the gate electrode 9. Therefore, even if the antireflection films 7, 18 which are constituted of Sign system thin films are kept existing, hydrogen is prevented by the Ti layer 5 included in the gate electrode 9 from reaching the gate insulating film 3.

EL 979978909

Coverage of patent
Claim 1
A semiconductor device whose substrate is constituted of a gate insulation film, a gate electrode, a nitrogen oxide silicon system thin film, and wiring system and its gate electrode contains a titanium layer.

Claim 2
This semiconductor device is characterized by containing a gate insulation film which is made from a silicon oxide system film on the substrate.

Claim 3
This semiconductor device is characterized by containing a gate electrode with a titanium silicide layer.

Claim 4
This semiconductor device is characterized by containing a nitrogen oxide silicon system thin film which is an antireflection film for patterning the gate electrode, and is laminated with the same pattern as the gate electrode.

Claim 5
The nitrogen oxide silicon system thin film in the claim 4 is an antireflection film for patterning the wiring system, and is laminated with the same pattern as the wiring system's.

Explanation
0001
Industrial use – This semiconductor device has patterning used by a nitrogen oxide silicon system thin film as an antireflection film. Therefore, it prevents from going bad, an electrical characteristic, due to hydrogen diffusion.

0002
Conventional technique – For wiring materials of semiconductor devices, aluminum (A1) system alloy or high melting point metal silicide are widely used. However, these materials are highly reflecticve and are required to put an antireflection film on the surface of the layers in order to improve the precision of photo lithography. As the design rules of semiconductor devices are regulated in detail, the exposure wavelength to the photo resist coating film has shifted to short wavelength side. On top of that, it is getting hard to obtain a stable resolution on these highly reflected materials because the size of the pattern is close to the exposure wavelength.

0003
Especially when a strong monochromatic light source such as the Excimer laser is used it is necessary to put an antireflection film because Standing Wave Effects change shape or width of wiring of the resist pattern.

0004
For the antireflection film, the use of a nitrogen oxide silicon (SiON) system thin film attracts a great deal of attention as it can control optic constant. The SiON system thin film can be produced by the plasma CVD method, and it is possible to be applied to the photo lithography using the Excimer laser because the optic constant is controllable by changing hydrogen contents in the film.

0005
Now, giving an example of an MOS transistor with the antireflection film. As in the chart 6, on a Si substrate 1, element isolation regions 2 and a gate insulation film 3 are formed. A gate electrode 109 constituted by a polysilicon layer 4 and a tungsten silicide layer 105 is formed above the film 3. The antireflection film 7 is formed on top and the sidewalls 10 are formed on both sides of the gate electrode 109. The antireflection film 7 is composed by a SiON system thin film. On the upper part, a SiO system interlayer insulation film 11 and A1 system wiring layers 17 are arranged.

0006

The A1 system wiring layers 17 electronically connect with the source/drain domains 12 on the Si substrate through the contact holes 13 of the SiO system interlayer insulation film. The A1 system wiring layers 17 also electronically connect with the gate electrode 109 through a contact hole 14. Furthermore, a titanium (Ti) film 15 and a nitrogenous titanium (TiN) film 16 are arranged as the barrier metals on the lower layer of the A1 system wiring layer 17, and an antireflection film which is composed by a SiON system thin film is arranged on the top of the A1 system wiring layers 17.

0007

As mentioned above, for the MOS transistor, the antireflection film 7 is laminated with a common pattern of the gate electrode 109 and the antireflection film 18 is laminated with a common pattern of the A1 system wiring layers 17.

0008

The antireflection film 7 is used in the photo lithography for patterning the gate electrode 109. To be more specific, after composing the polysilicon layer 4 and the tungsten silicide layer 105 on the Si substrate 1, the antireflection film 7 is made before constituting a photo resist coating film 8. Then the exposure for the photo resist coating film 8 is selected while the strong reflection lights from the tungsten silicide layer 105 are cut across. After the exposure selection and the developing process, the photo resist pattern is constituted. Making this pattern as a mask, the gate electrode 109 is able to be constituted to whatever the shape by etching the antireflection film 7, the tungsten silicide layer 105 and the polysilicon layer 4 (refer chart 7).

0009

In addition, because the antireflection film 7 exists after the patterning of the gate electrode 109, it is capable to cut across the reflection light from the tungsten silicide layer 105 again as photo lithographying for opening the contact holes 13 and 14 in the SiO system interlayer insulation layer 11.

0010

In this case, the antireflection film 7 is arranged to prevent the reflection lights from the tungsten silicide layer 105. In case of using the Excimer laser, which is a short wavelength light exposure, an antireflection film is also arranged when a gate electrode which is composed only by polysilicon layers is patterned for its highly reflection rates.

0011

On the other hand, the antireflection film 18 on the A1 system wiring layers 17 has the same pattern as the layers 17, and it is used for the photo lithography for the patterning of the layer 17. As in the chart 8, after opening the contact holes 13 and 14 to the SiON system interlayer insulation film, a Ti film 15 and a TiN film 16 are made as barrier metals. In forming a photo resist coating film 19, the antireflection film 18 is made. Preventing strong reflection lights from the A1 system wiring layers 17 by the antireflection film 18, the selection exposure to the photo resist coating film 19 is conducted. After the selection, using the photo resist pattern constituted in the developing process as a mask to etch the antireflection film 18, the A1 system wiring layers 17, the Ti film 15 and the TiN film 16, the A1 system wiring layer 17 are formed as shown in the chart 6.

0012

In addition, by existing of the antireflection film 18 after the patterning of the A1 system wiring layers 17, a SiO system interlayer insulation film is formed. If the SiO system interlayer insulation film gets photo lithography for opening the beer hall, the antireflection film 18 once again prevents strong reflection lights from the A1 system wiring layers 17.

0013

Problems to be solved – As mentioned above, the antireflection films 7 and 18 are also used for patterning of the material layers on the A1 system wiring layers 17 after its patterning. Therefore, these antireflection films are used in the MOS transistor. However, a SiON system thin film which composes the antireflection films 7

and 18 contains 20 percent of hydrogen, and diffuses the hydrogen during the heating process of impurities such as active anneal. The diffused hydrogen may decay the tolerance of "hot carrier" when it reaches the gate insulation film 3.

0014
To prevent this, one possible way is to etch removal whenever the antireflection film is used. However, in that case, it may be difficult to get the selection rate between the antireflection film and the material layers beneath the film, or it is necessary to produce an antireflection film every time the photo lithography occurs because the same antireflection film can be used only once.

0015
So, this device is invented to solve such problems and has a structure that is possible to prevent hydrogen diffusion to a gate insulation film with existence of an antireflection film which is composed by a SiON system thin film.

0016
Steps to solve the problems – This semiconductor device is invented to solve the problems mentioned above, and has a substrate constituted by at least a gate insulation film, a gate electrode, a SiON system thin film and an upper wiring layer. The gate electrode of this semiconductor device contains a Ti layer, which works well especially when a gate insulation film which is composed by a SiO system material film is constituted on the Si substrate.

0017
Usually, a gate electrode is composed by either polysilicon layers or amorphous layers and high melting point metal silicide is laminated for low resistance. The gate electrode in this device is constituted by a Ti layer which is laminated on top of either polysilicon layers or amorphous layers. Because the Ti layer is a conductive material it works as a part of the electrode. However, it also works as a trap to prevent reaching hydrogen to the gate insulation film as the Ti layer absorbs the hydrogen diffused from the SiON system thin film.

0018
The titanium silicide layer is preferred to be contained in the gate electrode. If the titanium silicide layer is arranged on top of a polysilicon layer or an amorphous layer, the gate electrode becomes polycide constitution which keeps resistance low.

0019
To constitute a titanium silicide, it is possible to use CVD to make a film as titanium silicide layers. But it is easy to make a Ti film on the polysilicon layer or the amorphous layer, and to do the Ti silicidation on both layers' surfaces after the heating process. In this process, there is no productivity problem compared to the process of the gate electrode with normal polycide constitution. Nevertheless, it is necessary to regulate the thickness of the film and the condition of the heating process to prevent consuming the polysilicon layers or the amorphous layers and the Ti layers when the silicidation is conducted.

0020
Now, when a SiON system thin film is produced with the plasma CVD, the optical invariable can be controlled as atomic formation rate can be adjusted based on the rate of gas flow. Therefore, when the SiON system thin film with the appropriate thickness is arranged as an antireflection film, it is possible to get the right exposure according to the underneath layer or the light.

0021
For the photo lithography to fully patterning the gate electrode, it is convenient to use a SiON system thin film as an antireflection film to prevent the reflection light from the material layers composing the gate electrode. If the antireflection film is retained after the photo-lithography, the film will be laminated with the same pattern

as the gate electrode.

0022
For the photo lithography in order to patterning the upper wiring, it is very convenient to use a SiON system thin film as an antireflection film to cut across strong reflection lights from the upper wiring. If the antireflection film is retained after the photo lithography, the film is laminated with a common patterning as the upper wiring's. If the photo lithography for patterning the interlayer insulation film is conducted on the upper wiring, the retained antireflection film cuts across the reflection light from the upper wiring again.

0023
Nevertheless, if a Ti film is arranged as a barrier metal at forming of the upper wiring, the amount of hydrogen from the SiON system thin film to the gate insulation film is very little, because the Ti film absorbs hydrogen.

0024
Effect – Because the Ti layer absorbs hydrogen in nature, it is difficult for hydrogen to reach the gate insulation film when this device is applied and the Ti layer is used as part of the gate electrode. The hydrogen is diffused from the SiON system thin film arranged above the gate electrode. Therefore, the Ti layer increases the reliability of the semiconductor device even though the gate insulation film is made from the SiON system materials because the film develops hot carrier resistance.

0025
If the gate electrode contains titanium silicide layers, it is possible to have relatively low resistance.

0026
This semiconductor device never gets inferior in quality of hot carrier resistance in any ways when the SiON system thin film is used as the antireflection film. The reasons are following.

0027
In the gate film it is important to control the film quality in the area which is connected to a channel domain. The channel domain is constituted between the source domain and drain domain, so it is controlled depending on the extent of the both domains. Usually, both domains are organized when impurities are put into a substrate and then they are activated and diffused. Therefore, the channel domain exists relatively inside the edge of the gate electrode. In this semiconductor device, because a Ti layer has the same patterning as the gate electrode's, a gate insulation film which connects to the channel domain is protected by hydrogen from the SiON system thin film on the gate electrode and the SiON system thin film on the upper wiring layer. If the quality of the gate insulation film is maintained well, it is possible to improve the hot carrier resistance.

0028
Example – Examples are given referring to the charts.

0029
This semiconductor device is applied to the MOS transistor and has a construction that prevents hydrogen to reach the gate insulation film from the SiON system thin film used as the antireflection film.

0030
As in the chart 1, this MOS transistor has a Si substrate 1 which is constituted by an element isolation region 2 and the gate insulation film 3. On the substrate, a poly-silicon layer 4 and a Ti layer 5, and a gate electrode 9, which is composed by titanium polycide layers arranged between the poly-silicon layers 4 and the Ti layers 5, are formed. The gate electrode 9 is laminated with an antireflection film 7 which is made from the SiON system thin film with the same patterning as the gate electrode's. The sidewalls 10 are arranged on the both surfaces of the gate electrode. In addition, a SiO system interlayer insulation film 11 and A1 system wiring layers 17 are arranged on top of the gate electrode. The A1 system wiring layers 17 are electronically connected to the source/drain domains 12 through the contact hole 13. The layer 17 also electronically

connects to the gate electrode 9 through the contact hole 14.

0031
A Ti film 15 and a TiN film 16 are arranged underneath the Al system wiring layer 17 as barrier metals. An antireflection film 18 made from the SiON system thin film is laminated on the layer 17. The antireflection film 18 has the same patterning as the layer 17's.

0032
According to the special quality check, this MOS transistor has much superior hot carrier resistance to the current MOS transistor whose gate electrode does not contain the Ti layer 5. Based on this factor, it is found that the Ti layer 5 in the gate electrode 9 prevents hydrogen to the gate insulation film 3 even though the antireflection film 7 is retained.

0033
The production process of the above MOS transistor is referred to the chart 2 through 5.

0034
As in the chart 2, a poly silicon layer 4, an N-shaped constitution material layer of the gate electrode 9, with a titanium silicide layer 6 and a Ti layer 5 are formed on the Si substrate which is constituted by element isolation region 2 and the gate insulation film 3. The antireflection film 7 and a photo resist coating film 8 are added on top.

0035
In details, the thickness 270 nm of the element isolation region 2 is constituted with the selection oxidization in the LOCOS method, and the gate insulation film 3 is constituted by heat oxidization of 850 C under H2 gas and O2 gas. Then, the poly silicon layer 4 is made with the sickness 70 nm by the CVD at 550 C with SiH4 and PH3 gas. And the Ti layer 5 is made with thickness from 30 to 100 nm by spattering.

0036
A titanium silicide layer 6 is formed by the Ti's silicidation on the interface between a poly silicon layer 4 and a Ti layer 5 from the Rapid Thermal Anneal (RTA) at 600 C for 30" and at 800 C for 20". Then an antireflection film 7, which is constituted by the SiON system thin film is made over the Ti layer 5 by the plasma CVD using SiH4 and N4O at 360 C. The photo resist coating film 8 is formed after that. Now, the optic constant of the antireflection film 7 is set at 2.10 for the actual number n in the complex refractive index, and at 0.62 for the coefficient k in the imaginary number.

0037
As in the chart 3, the patterning of the gate electrode 9 is conducted. In detail, a selection exposure for the photo resist coating film 8 is conducted with 248 nm of wavelength exposure light while the antireflection film 7 prevents the strong reflection lights from the Ti layer 5. Then Reactive Ion Etching (RIE) is conducted to the antireflection film 7, the Ti layer 5, the titanium silicide layer 6 and the poly silicon layer 4 with the photo resist pattern which is formed through the developing process. Based on this, the gate electrode 9 is constituted with a desired configuration pattern. The antireflection film 7 is not removed and is kept on the gate electrode 9.

0038
As in the chart 4, the formation of the side wall 10 and the SiO system interlayer insulation film 11 follows. The side wall 10, which covers the both surfaces of the gate electrode 9, is formed by anisotropic etching after filming a 150 nm of the SiO2 layer by CVD. Then, the SiO system interlayer insulation film 11 with sickness of 300 nm is made by CVD.

0039
As in the chart 5, the Al system wiring layers 17 which electronically connect to the source/drain domains 12,

and the gate electrode 9 is constituted.

0040
First of all, the contact hole 13 to the source/drain domains 12 and the contact hole 14 to the gate electrode 9 are opened by photo lithography and etching to the SiO system interlayer insulation film 11. The antireflection film 7 is also used for the photo lithography to prevent the reflection light from the Ti layer 5.

0041
Subsequently, a Ti film 15 with thickness 30 nm and a TiN film 16 with thickness 70 nm are formed by spattering as if inside of the contact holes 13 and 14 are covered from the surface of wafer. Then the thickness 300 nm of the A1 system wiring layers 17 with 1 percent of Si is made by spattering as the inside of the contact holes 13 and 14 are filled in. The photo resist coating film 18 is formed after the antireflection film 18 with the thickness 23 nm on the A1 system wiring layers 17 in the same way of forming the antireflection film 7 on the gate electrode. The optic constant for the antireflection film 18 is set at 2.16 for the actual number n in the complex refractive index, and at 0.875 for the coefficient k in the imaginary number.

0042
The selection exposure for the photo resist coating film 19 is conducted with 248 nm of exposing light while the antireflection film 18 prevents strong reflection lights from the A1 system wiring layer 17 to the wafer, and the photo resist coating film 19 is constituted with a desired configuration pattern after the developing process. The Al system wiring layers 17 are constituted with a desired configuration pattern by etching the antireflection film 18, the A1 system wiring layers 17, the Ti film 15 and the TiN film 16 with RIE. Then, the photo resist coating film 19 is removed and annealing is conducted at 400 C in N2 gas which contains 2 percent of H2 gas. The MOS transistor is completed as shown in the chart 1.

0043
Now, because the antireflection film 18 is not removed, it is kept on the A1 system wiring layer 17. The film also prevents the reflection lights when the patterning for opening the beer hall to the SiO system interlayer insulation film.

0044
The application of this semiconductor device is not limited to the above examples and it is possible to change to other usage. Because the Ti layer 5, which absorbs hydrogen diffused from the antireflection film, is constituted as part of the gate electrode 9, the antireflection film can be kept in any positions as long as it is above the Ti layer 5. The position of the antireflection film is not limited on the gate electrode 9 or on the A1 system wiring layers 17. Of course, if the antireflection film 7 is not necessary for the patterning the gate electrode 9 as the size of the pattern is big, the film does not have to be put on such position. Also the constitution of the wafer and the condition of filming are not limited to the above examples. For example, it is possible to make an amorphous silicon layer instead of a poly silicon layer in the gate electrode 9.

0045
Effect - With this semiconductor device, because hydrogen diffused from the SiON system thin film hardly reaches the gate insulation film, the hot carrier has strong resistance of keeping the SiON system thin film. In other word, the hot carrier of this semiconductor device has superior in resistance to that of the conventional semiconductor device.

0046
The titanium layer, constituting a part of the gate electrode, can be formed easily on the interface between the Ti layer and the poly silicon layer or the amorphous silicon layer by heating process. Therefore, the titanium layer keeps the gate electrode's resistance low by forming the titanium silicide layer.

0047
In addition, because this semiconductor device prevents inferiority of hot carrier resistance for retaining the

SiON system thin film, the removal process for the SiON system thin film can be eliminated in the production process. The productivity is also good because the SiON system thin film can be recyclable to the next photo lithography by retaining the SiON system thin film.

0048
Applying this invention, it is possible to supply a very reliable semiconductor device without huge cost increasing. This invention has a high industrial value.

Explanation of the chart
Chart 1 – A cross section of the device.
Chart 2 – Showing the wafer process of the chart 1; formation of the titanium layer on the interface between the poly silicon layer and the Ti layer, and formation the antireflection film. It also shows the formation of the photo resist coating film.
Chart 3 – A cross section of the patterning the gate electrode.
Chart 4 – A cross section of the formation of side wall, source/drain domains, the SiO system interlayer insulation film.
Chart 5 – A cross section of the formation of the A1 system wiring layer electronically connecting to the gate electrode and the source/drain domains.
Chart 6 – A cross section of the conventional semiconductor device.
Chart 7 – Production process of wafer, filming the poly silicon layer and tungsten silicide layer and the antireflection film, and forming the photo resist coating film.
Chart 8 – A cross section of the formation source/drain domains and the SiO system interlayer insulation film at the wafer, and formation the A1 system wiring layer which electronically connects to the gate electrode and source/drain domains.

Code:
1 Si substrate
2 Element isolation region
3 Gate insulation film
4 Poly-silicon layer
5 Ti layer
6 Titanium silicide layer
7, 18 Antireflection film
8, 19 Photo resist coating film
10 Side wall
11 SiO system interlayer insulation film
12 Source/drain domain
13, 14 Contact hole
15 Ti film
16 TiN film
17 A1 system wiring layer